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TITLE	(54):	HIGH-STRENGTH HOT-ROLLED STEEL PLATE AND ITS MANUFACTURE
FOREIGN TITLE	[54A]:	KOKYODO NETSUEN KOBAN OYOBI SONO SEIZOHO

Specifications

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1. Title of the Invention

High-Strength Hot-Rolled Steel Plate and Its Manufacture

2. Claim

(1) A high-strength hot-rolled steel plate with outstanding moldability characterized by containing 0.02 to 0.2% of C, 0.7 to 2% of Si, 0.3 to 1.2% of Mn, 0.55 to 1.2% of Cr, and 0.005 to 0.1% of Al, with the S not more than 0.02%, the relationship between Si and Mn a ratio (Si%/Mn%) ≥1.1; and furthermore, comprising a ferrite and martensite composite structure, with the martensitic area of this composite structure being 1 to 80%.

(2) The hot-rolled steel plate of Claim 1 containing one or more of 0.05 to 0.2% of Mo, 0.1 to 0.5% of Cu, 0.1 to 0.5 [%] of Ni and 0.05 to 0.15% of P.

(3) The hot-rolled steel plate of Claim 1 or 2 containing one or more of 0.01 to 0.1% of Nb, 0.02 to 0.2% of V, 0.1 to 0.5% of Ti, and 0.02 to 0.2% of Zr.

(4) The hot-rolled steel plate of Claim 1, 2 or 3 containing one or more of 0.005 to 0.2% of a rare earth element and 0.005 to 0.01% of Ca.

(5) A method for manufacturing a high-strength, hot-rolled steel plate with outstanding moldability characterized by containing singly

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or a mixture of 0.02 to 0.2% of C, 0.7 to 2% of Si, 0.3 to 1.2% of Mn, 0.55 to 1.2% of Cr, and 0.005 to 0.1% of Al, with the S not more than 0.02% and the relationship between Si and Mn a ratio (Si%/Mn%) ≥1.1, and as further needed, at least one of 0.01 to 0.1% of Nb, 0.02 to 0.2% of V, 0.1 to 0.5% of Ti and 0.02 to 0.2% of Zr, at least one of 0.05 to 0.2% of Mo, 0.1 to 0.5% of Cu, 0.1 to 0.5 of Ni and 0.05 to 0.15% of P, and at least one of 0.005 to 0.2% of a rare earth element and 0.005 to 0.01% of Ca, hot rolling at a hot rolling finish temperature of 800 to 900°C, performing a controlled cooling at an average cooling speed of 5 to 80°C/sec. from the hot rolling finish temperature to between the Ar_1 point to 550°C, and performing a rapid cooling and coiling at an average cooling speed of 80°C/sec. or more between 350 to 500°C.

2. Detailed Specifications

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The present invention relates to a high-strength hot-rolled steel plate with outstanding shape retainability, in other words, excellent moldability wherein the elongation and flangeability are outstanding and the yield ratio (0.2% proof stress/tensile strength) is low.

Due to automobile safety measures in recent years, making vehicles more lightweight has become an important issue in reinforcing car bodies and fuel consumption economy. The use of various high-strength steel plates has been investigated as means for solving these conflicting problems. Of these, composite structure-type steel plates

have received attention recently. This composite-type steel plate is a composite structure containing systematically a ferrite phase and a low-temperature transformation structures (includes a martensitic structure, and a partial bainitic and residual austenitic structure), and it is a high-strength steel plate with a low yield ratio and improved moldability. However, the stretch flangeability of these composite structure-type steel plates is inferior to that of bainite steel, so even more improvement in moldability is required overall.

The present invention was achieved for the purpose of obtaining a steel plate whose stretch flangeability is improved even more while maintaining the benefits of a composite structure-type steel plate.

Namely, the present invention is a high-strength hot-rolled steel plate with outstanding moldability characterized by containing 0.02 to 0.2% of C, 0.7 to 2% of Si, 0.3 to 1.2% of Mn, 0.55 to 1.2% of Cr, and 0.005 to 0.1% of Al, with the S not more than 0.02%, the relationship between Si and Mn a ratio (Si%/Mn%) ≥1.1; and furthermore, comprising a ferrite and martensite composite structure, with the martensitic area of this composite structure being 1 to 80%.. Moreover, the steel plate of the present invention contains singly or a combination of, as needed, at least one of 0.05 to 0.2% of Mo, 0.1 to 0.5% of Cu, 0.1 to 0.5 of Ni and 0.05 to 0.15% of P, at least one of 0.01 to 0.1% of Nb, 0.02 to 0.2% of V, 0.1 to 0.5% of Ti, and 0.02 to 0.2% of Zr, and at least one of 0.005 to 0.2% of a rare earth element and 0.005 to 0.01%

of Ca.

Furthermore, the present invention is method for manufacturing a high-strength, hot-rolled steel plate with outstanding moldability characterized by hot rolling steel having the above-mentioned chemical constituents at a hot rolling finish temperature of 800 to 900°C, performing a controlled cooling at an average cooling speed of 5 to 80°C/sec. from the hot rolling finish temperature to between the Ar_1 point to 550°C, and performing a rapid cooling and coiling at an average cooling speed of 80°C/sec. or more between 350 to 500°C.

The present invention will now be explained in further detail.

As a result of performing detailed studies on the stretch flangeability, which is a drawback of steel with a composite structure, and the chemical constituents according to the present invention, it was proven that the relationship between Si and Mn was important.

Namely, as shown in Figure 2 of the below-mentioned practical example, when the weight ratio of the Si and Mn, i.e., Si%/Mn% is 1.1 or higher, the relationship between the strength and notch elongation (an index which indicates the stretch flangeability) is improved over a relationship at a weight ratio below that.

The reason for such a phenomenon is unexplained, but the following reason have been considered.

(1) The weight and length of the sulfide-based inclusions after adding Si are reduced.

There is also a large amount of Mn added; hence, the Si/Mn must be 1.1 or higher.

(2) The reinforcing effect of Si is higher than that of Mn according to the work-hardening exponent (n), and the stacking fault energy is reduced; hence, cell formation is slow, and as a result, the cell size also is decreased, and elongation and drawing are both excellent.

(3) Si functions to accelerate the concentration of C into the untransformed γ phase from ferrite, and as a result, it stabilizes the ferrite-martensite composite structure, and at the same time, increases the difference in the hardness of martensite and ferrite, and improve elongation by purifying the ferrite matrix.

The reason for limiting each of the chemical constituents in the steel of the present invention will now be explained.

0.02% or more of C is required for manifesting the effect for improving strength and quenchability. However, if an increase in the strength is planned with C, it is well known that the stretch flangeability worsens even at the same strength. If the amount of C is increased, there is the risk that the perlite area and a strip structure will be brought about. In steel having a composite /271 structure, the C in the martensite is concentrated; hence, the upper

limit of the C is more lenient than in the usual type of structure, but upon considering the meltability as well, the upper limit is made 0.2%, and when moldability is especially demanded, it is made 0.14% or less.

Besides the fact that Si plays a role in the deoxidation of molten steel, it is an element which enables an increase in strength while keeping the deterioration of the cold moldability low, and it also functions to impart high drawability. It is an element essential for further improving the stretch flangeability, as stated above.

Moreover, it has a function for accelerating the α transformation during a γ-α transformation after hot rolling or annealing in a steel with a composite structure as in the present invention, and at the same time, eliminating the α solid-solution carbon into γ. As a result, the purity of the α phase is increased, and moreover, γ stabilization is planned by concentration of the carbon into the γ and the formation of martensite becomes easy; hence, the mechanical properties are improved. Thus, it is necessary to increase [the amount of Si] to 0.7% or higher. However, if too much of it is added, there is the risk that the ferrite area will expand too far, inviting embrittlement of the weld zone; hence, the upper limit is 2%.

Mn is an element required for fixing the S and preventing hot brittleness.

In addition, Mn is also an effective element for increasing strength, but it is not as effective as Si. Moreover, there is the risk that it could adversely affect the control of the sulfide form and invite an increase in the perlite area; hence, the upper limit of the amount of Mn is 1.2%. Moreover, the Mn is an element required for improving the quenchability, stabilizing the γ phase during γ-α transformation and improving the mechanical properties. Sometimes it is combined with Si and Cr, but adding at least 0.8% of it is desirable.

Cr does not contribute anything, but it is an element used for gauging the higher strength and mechanical properties due to the effect for improving quenchability. Moreover, the Cr has a function for accelerating the concentration of the C to γ. For this purpose, the lowest amount is 0.55% is required, but when a large amount of Si is contained, as in the steel of the present invention, up to 1.2% of it is plenty. Addition of an amount higher than that is undesirable since the amount of martensite becomes too high, the ductility deteriorates, and moreover, costs increase.

Al plays a role as a deoxidizer during melting and 0.005% to 0.1% of it is contained.

S forms a sulfide which worsens the ductility; hence, it is set to at most 0.02%, and desirably, at most 0.015% in order to alleviate this detriment.

Otherwise, according to the present invention, the following elements can be contained, as needed.

Mo, Cu, Ni and P have functions for stabilizing austerite and easily obtaining a hot-rolled steel plate with a composite structure.

In order to obtain these effects, addition of an amount greater than the lowest limit is required, and the respective amounts are determined for the best effects or because costs increase rapidly. Namely, a total of 0.6% or less of one or more of 0.05 to 0.2% of Mo, 0.1 to 0.5% of Cu, 0.1 to 0.5% of Ni, and 0.02 to 0.15% of P can be contained.

The carbonitride-forming elements Nb, V, Ti and Zr have a precipitation hardening effect and an effect for refining the ferrite particles, and they are effective elements for hardening without reducing the brittleness and stretch flangeability.

Ti and Zr also are effective for controlling the sulfide form, and they are contained in the following ranges in order to obtained such effects. Namely, a total of 0.25% or less of one or more of 0.01 to 0.2% of Nb, 0.02 to 0.2% of V, 0.01 to 0.1% of Ti, and 0.02 to 0.2% of Zr may be contained.

Rare earth metals (REMs) or Ca function in defusing the inclusions due to Ti and Zr effects for controlling the sulfide form, and increasing the moldability. In order to obtain this effect, a total of 0.2% or less of one or more of about 0.005 to 0.2% of REM,

and 0.005 to 0.01% of Ca are contained.

The area ratio of the martensite in the composite structure of ferrite and martensite (sometimes part perlite and residual austenite) will now be described. As shown in Fig. 4, the yield ratio greatly depends on the martensite area ratio. In order to maintain a low yield ratio, which is a property of a composite structure-type steel, it is necessary to make the martensitic area ratio 1 to 80%, and desirably, 8 to 15%.

The method of the present invention will now be explained.

The method for manufacturing the steel plate with a /272 composite structure according to the present invention is a method for making a hot-rolled steel with a composite structure as is by controlling the hot rolling conditions and then the cooling conditions.

First of all, a basic approach thereof will be explained according to Fig. 1.

In Fig. 1, hot rolling of a steel slab with the prescribed constituents is started at T_1 and the hot rolling is finished at T_2 (hot rolling finishing temperature). After the hot rolling is finished, it is subjected to a controlled cooling to T_3 (temperature at which cooling speed is changed) at a cooling speed of C_1 (controlled cooling speed). After the controlled cooling, it is rapidly cooled from T_3 to T_4 (coiling temperature) at a cooling speed

of C_2 (rapid cooling speed), and coiled at T_4.

The mechanism from a metallurgical standpoint for changing the steel in this manufacturing process is as follows. First of all, in the process from T_1 to T_3 exists the range in which the majority ferrite phase and the residual austenite phase coexist. Due to the relative slow cooling in this interval, the solid-solution carbon in the ferrite is concentrated into austenite, γ stabilization is planned, and at the same time, a ferrite phase with little solid-solution C is purified; hence, the ductility is improved and strain aging is prevented due to the solid-solution C. Furthermore, there is even a preliminary stage for obtaining a more desirable second phase proportion, which is important for this process. The process from T_3 to T_4 is one for making the untransformed γ having the above-mentioned concentrated carbon next. A faster cooling speed than C_1 is required. Furthermore, T_4 is an important temperature for making the untransformed γ a low-temperature transformation product, but the stability of γ is high in the steel of the present invention; hence, the necessary amount of martensite also is ensured even when coiled at 350 to 500°C.

Next, the respective temperatures and cooling rates in the manufacturing process of the present invention described above will now be explained specifically on the basis of experimental facts. A steel slab in which the C, Si, Mn, and the like are adjusted with the

prescribed constituents is prepared, this slab is heated, hot rolling is performed, and a hot-rolled steel plate is obtained. This hot rolling finishing temperature (T_2) is one (1) point of the present invention. By appropriately doing the subsequent controlled cooling, even without particularly limiting the temperature close to 750°C, outstanding properties are even obtained at a higher temperature finishing (in other words, the usual hot rolling finishing) temperature. Consequently, it is thought that the shape of the plate easily deteriorates by increasing the sheet crown quantity and the like due to a low-temperature rolling, so the hot rolling finishing temperature was limited to 800 to 900°C.

After hot rolling, the steel plate is cooled to T_3, but the cooling speed C_1 is an important point of the present invention until T_3. Namely, in order to obtain the desired composite structure, in a CCT graph, the cooling speed in this range, which is the cooling speed between perlite and an intermediate structure (bainite), is reduced, and a ferrite-perlite structure is obtained and the desired mechanical properties, as mentioned above, are not obtained. However, if the ferrite area in the ferrite-bainite structure is 60 to 80%, and desirably, at least 80%, this temperature is not limited.

The reason for this is because untransformed γ remains in the bainite structure during γ-α transformation, and this γ is transformed to martensite in the subsequent cooling process.

C_1 is a cooling speed at 5 to 30°C/sec. according to the present invention. At this cooling speed, this is a structure in which the ferrite formed sufficiently during cooling to T_3 and the untransformed γ coexist, but this temperature (the T_3) also is an important point. Namely, if the T_3 is increased, the ferrite, which is the parent phase is not formed sufficiently, and there is more than the necessary proportion of the second phase; hence, the ductility is compromised. In addition, if the T_3 is lowered, there is the risk that the aforesaid untransformed γ will be transformed to bainite or perlite at C_1. It is necessary to not lower it more than necessary since the desired mechanical properties will not obtained, a reduction in the productivity will be brought about, etc. The T_3 ranges from Ar_1 to 550°C on the basis of these experimental facts. The structural constitution for obtaining the desired mechanical properties have been roughly determined, but now, more importantly, not only is the carbon in the ferrite eliminated into austenite by relatively slowly cooling at C_1, or 5 to 30%/sec. and γ stabilization is planned by concentration of the carbon, the ductility is improved and strain aging is prevented since ferrite with little solid-solution carbon can be purified.

Furthermore, the cooling speed C_2 between T_3 and T_4 is for transforming the untransformed γ to hard martensite, that is, for obtaining a ferrite-martensite structure. According to the present /273

invention, the C_2 is 30°C/sec. or higher, and desirably, 30 to 90°C/sec. It is necessary that the strength of the second phase be as hard as possible, but it is not necessary to hasten C_2 more than necessary for that reason. When the carbon concentration in the untransformed ferrite is produced sufficiently between the above-mentioned T_2 and T_3, and as long as the untransformed γ is small, the carbon concentration in the γ is increased in a balanced manner. In this state, the second phase can be made a sufficiently hard phase in order to obtain the desired mechanical properties even if the C_2 is relatively slow.

The steel plate is subsequently coiled at a prescribed coiling temperature, but this coiling temperature (T_4) also is an important point in the present invention. That is, in order to prevent softening of the second phase by tempering, it is desirable to cool it to room temperature at C_2, but deterioration of the ductility and strain aging, a decrease in productivity, and the like due to solid-solution carbon remaining in the process to T_4 are prevented. Moreover, in order to better the coiled shape of the coil, it is desirable to coil it at 350 to 500°C. By making the structure of the steel plate a composite structure with a hard, low-temperature transformation structure (martensite and partial bainite) in the method described above, and making the volume of the second phase at that time 10 to 80%, and preferably, 10 to 20%, a high-strength, hot-

rolled steel plate with an outstanding balance between a low yield ratio and a strong ductility is obtained inexpensively.

The steel plate of the present invention can be manufactured according to the method as described above, but the steel plate of the present invention also can be obtained in a continuous annealing method, etc.

The practical examples of the present invention are shown next along with the comparative examples.

After hot rolling of the steel with the constituents shown in Table 1 at the hot rolling finishing temperature (T_3) 825°C was finished, it was coiled by cooling it to 600°C (T_3) onward at 20°C/sec. (C_1) and from 600°C at 60°C/sec. (C_2). The coiling temperature was 400°C for steel nos. 1 to 6, 450°C, for no. 7, 360°C for no. 8, 350°C for no. 17, and 250°C for nos. 18 and 19. Moreover, C_1 is 30°C/sec. for steel no. 17, and C_1 is 60°C/sec. and C_2 is 60°C/sec. for steel no. 18; these speeds vary for the other steel. The mechanical properties and the structure of the steel plate obtained in this way are shown in Table 2.

The yield ratio (yield stress/tensile strength) and the strength and elongation balance (T.SXE1) here are often used as indices indicating moldability. It is thought that the lower the yield ratio and the higher the value of the strength/elongation balance, the more outstanding the shape retainability and moldability are.

The yield point elongation is related to the emergence of a wrinkle pattern in parts sustaining a tensile stress during working. The lower the value of the yield ratio strength the better it is for forming the same pattern. Notch elongation shows the boundaries at which shaping can be done without cracks developing while sustaining a stretch-flanging molding, as with bolt hole molding for wheel disks. It is thought that the stretch flangeability is outstanding.

Table 1

Steel No.	Chemical constituents (% by weight)									Notes
	C	Si	Mn	P	S	Al	Cr	Si/Mn		
1	0.05	1.2	1.0	0.015	0.007	0.02	0.85	1.2		Steel of the present invention
2	0.05	1.2	1.0	0.11	0.005	0.03	0.85	1.2		
3	0.08	1.2	0.9	0.020	0.004	0.02	0.85	1.3	Cu 0.02	
4	0.06	1.2	1.0	0.015	0.006	0.02	0.55	1.2	Mo 0.15, Cu 0.2, Ni 0.2	
5	0.05	1.2	0.9	0.015	0.006	0.02	0.75	1.3	Nb 0.03	
6	0.05	1.2	0.9	0.010	0.006	0.02	0.58	1.3	Ti 0.08 Y 0.05	
7	0.06	1.2	1.0	0.015	0.007	0.02	0.90	1.2	Nb 0.02, Zr 0.1	
8	0.08	1.2	0.9	0.015	0.005	0.02	0.55	1.3	Nb 0.03	
9	0.06	1.5	1.0	0.016	0.006	0.02	0.70	1.5		
10	0.06	0.8	0.7	0.015	0.005	0.02	1.1	1.14		
11	0.05	0.3	1.5	0.015	0.008	0.02	1.2	0.2		Steel for comparison
12	0.05	1.2	1.0	0.015	0.040	0.03	0.8	1.2		
13	0.28	1.2	1.0	0.015	0.008	0.02	0.9	1.2		
14	0.05	1.2	1.0	0.015	0.008	0.02	1.6	1.2		
15	0.06	1.2	1.0	0.015	0.008	0.02	0.8	1.2		
16	0.05	0.5	0.2	0.015	0.008	0.02	0.6	2.5		
17	0.05	1.7	1.5	0.015	0.008	0.08	1.1	1.13		
18	0.05	0.1	1.2	0.015	0.005	0.02	0.5	0.08		
19	0.05	0.4	0.7	0.016	0.004	0.02	0.9	0.57		

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Table 2

	Yield stress kg/mm²	Tensile strength kg/mm²	Elongation %	Yield point elongation %	Yield ratio %	TS×El	Notch elongation %	Structure	Notes
1	38.3	60.5	30.7	0	53	1857	10.5	F + 3 % M	Present invention
2	34.5	61.3	30.2	0	56	1851	10.8	F + 3 % M	
3	32.9	60.3	31.3	0	55	1887	11.5	F + 7 % M	
4	41.4	69.0	25.3	0	60	1745	7.8	F + 30 % M	
5	40.2	68.2	25.8	0	59	1789	8.4	F + 15 % M	
6	38.8	67.7	26.5	0	58	1794	8.5	F + 10 % M	
7	37.9	65.5	27.5	0	58	1801	5.8	F + 20 % M	
8	37.9	62.3	29.6	0	61	1844	9.7	F + 25 % M	
9	35.0	63.7	29.8	0	55	1898	10.8	F + 5 % M	
10	28.9	53.3	30.7	0	54	1608	12.0	F + 3 % M	
11	34.4	62.5	26.4	0	55	1650	8.7	F + 15 % M	Comparative examples
12	32.8	60.0	29.8	0	55	1788	8.0	F + 3 % M	
13	58.3	85.8	14.6	0	68	1252	8.5	F + 50 % M	
14	50.0	79.5	15.4	0	63	1800	4.2	F + 40 % M	
15	36.4	48.5	33.3	2.7	75	1618	13.5	F + P	
16	25.5	35.0	42.5	3.8	73	1488	15.4	F + P	
17	52.3	82.5	20.6	0	64	1699	4.5	F + 40 % M	
18	36.5	56.2	29.2	0	65	1641	9.0	F + 8 % M	
19	35.9	55.3	30.1	0	65	1664	10.0	F + 10 % M	

In Table 2, it is already known that the influence of the amount of Cr is large. That is, the steel no. 15 of the present invention in which the amount of Cr is too low is a hot-rolled ferrite-perlite structure as is, yield point elongation develops, and the yield ratio also is high. If the amount of the Cr is too high (steel no. 14) the strength is too high, the yield ratio is high, and the elongation decreases. All of the steel whose Cr quantity is within the range of the present invention show outstanding elongation and a low yield ratio, and they comprise a majority fine polygonal ferrite, a little

martensite, and residual austenite.

The stretch flangeability of the steel no. 11 with a Si/Mn lower than the lower limit of the present invention is more inferior than the steel having the range of the present invention. The results for the stretch flangeability have been shown in Table 2. As seen from Fig. 2, all of the high-strength hot-rolled steel plate of the present invention have more outstanding stretch flangeability at the same level of strength than the hot-rolled steel plate of the comparative example. The stretching flangeability can be improved if the amount and the shape of the inclusions are controlled by adjusting the weight ratio of the Si and Mn added after reducing the amount of S to at least 1.1. Moreover, if a rare earth element, such as Ce, is added, as in steel no. 3, not only the stretch flange property but also molding can be improved.

The steel no. 16 wherein the amounts of Si and Mn are lower than the lower limit of the present invention is typically ferrite-perlite; the yield ratio is high and the strength is low.

Steel no. 4 is an example of the present invention in which Mo, Cu and Ni, which have action for strengthening or stabilizing austenite, are added to the basic constituents. It has a lower yield ratio and more excellent elongation at a high coiling temperature than a steel with the basic constituents.

Steel nos. 5 to 7 are examples of the present invention in which Nb, Ti, and the like having precipitation hardening, and a fine grain reinforcing action is added to a steel with the basic constituents. In spite of the high strength, the elongation, and especially, the stretch flangeability is more outstanding than a steel with basic constituents.

Moreover, the relationship between the amount of martensite and the yield ratio of the ferrite and martensite structural steel is shown in Fig. 8 and Table 2, but as understood from Fig. 3, the amount of martensite (area) ranges from 1 to 30%, and a low yield ratio is maintained.

4. Brief Description of the Figures

Figure 1 is a drawing conceptually showing the manufacturing method in the present invention; Figure 2 is a drawing showing the tensile strength and the notch elongation of the steel of the present invention and the steel for comparison; and Figure 3 is a drawing showing the relationship between the martensitic area ratio and the yield ratio for the ferrite and martensite structural steel.

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Figure 1

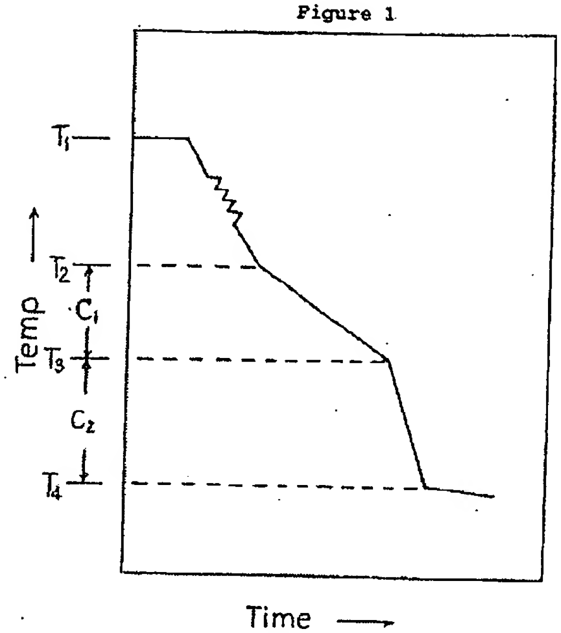

Figure 2

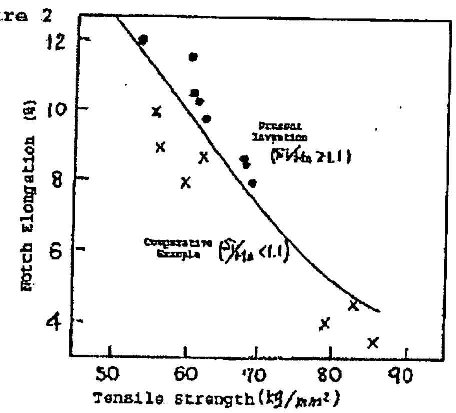

Figure 3